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Lab. Project 930-76, Progress Report 3  
SF 020-01-02, TASK 0727

**Effects of Chemical Composition  
And Heat Treatment  
On the Sea Water Corrosion Resistance  
Of Cast Modified Nickel-Aluminum Bronze**

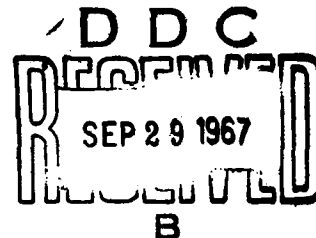
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August 1967



**U. S. NAVAL APPLIED SCIENCE LABORATORY  
BROOKLYN, NEW YORK**

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EFFECTS OF CHEMICAL COMPOSITION  
AND HEAT TREATMENT  
ON THE SEA WATER CORROSION RESISTANCE  
OF CAST MODIFIED NICKEL-ALUMINUM BRONZE

Lab. Project 930-76, Progress Report 3

SF 020-01-02, TASK 0727

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#### SUMMARY

Flowing sea water corrosion tests were conducted on four modified cast nickel-aluminum bronzes in order to determine the effects of variation in alloy composition and heat treatment on pitting corrosion tendencies. It was found that the aluminum and iron contents controlled the pitting corrosion resistance of these alloys. A proper balance of the major alloying elements appeared necessary to insure adequate corrosion resistance. Heat treatment at 1300°F and 1400°F improved the overall corrosion resistance over that of the as-cast alloys. For these modified compositions it was observed that slow cooled cast material displayed better as-cast corrosion resistance than fast cooled material.

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ADMINISTRATIVE INFORMATION

- Ref: (a) NAVAPLSCIENLAB Program Summary of 1 May 1967,  
SP 020-01-02 Task 0727  
(b) NASL Project 6355, Progress Report 1 of 25 Oct. 1963  
(c) NASL Project 6355 Technical Memorandum #1 of 17 Apr. 1964  
(d) NASL Project 6355 Technical Memorandum #3 of 26 May 1965  
(e) NASL Project 6355 Technical Memorandum #7 of 17 Sep. 1965  
(f) NASL Project 6355 Technical Memorandum #8 of 4 Apr. 1966  
(g) NASL Project 930-76(1) Progress Report #2 of 5 Jul. 1967  
(h) Military Specification MIL-B-23921, Amendment 2 of  
25 July 1966  
(i) Federal Test Method Standard No. 151a of 6 May 1959

1. In connection with the U. S. Naval Applied Science Laboratory's (NASL) Program on Fabrication of Non-Ferrous Machinery Alloys, outlined in reference (a), the Laboratory is conducting an investigation on the deterioration of aluminum bronze casting alloys in sea water due to dealuminization attack, with particular emphasis on the effects of heat treatment and welding on this corrosion phenomenon.

BACKGROUND

2. Previous Laboratory work on the dealuminization tendencies of aluminum and nickel-aluminum bronze casting alloys in flowing sea water was reported in references (b) through (g) which dealt with alloys governed by Military Specifications MIL-B-16033 and MIL-B-23921. As-cast aluminum bronzes, MIL-B-16033 Classes 1, 2 and 3, exhibited significant losses in tensile strength due to dealuminization of the inter-connected microstructural network of aluminum-rich beta and alpha plus gamma-2 eutectoid phases.

Note: (1) Laboratory Project 930-76 was formerly designated Laboratory Project 6355.

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3. A duplex heat treatment (1625°F (2 hr) W.Q.-1125°F (1½ hr) W.Q.) was successful in breaking up and dispersing the interconnected aluminum-rich phases and thus improved the dealuminization corrosion resistance of the alloys. However, the duplex type heat treatment is costly and the benefits derived from this thermal treatment are nullified when weld repairs are made.

4. The MIL-B-16033-Class 4 alloy contains significant alloying additions of nickel and iron which tend to suppress the formation of the alpha plus gamma-2 eutectoid (continuous aluminum-rich networks) in the as-cast microstructure. When this alloy was investigated by NASL, it was found that after one year in sea water the as-cast material was subject to dealuminization. It was concluded that while the Class 4 alloy contained substantial alloying additions, the specified aluminum content (10.0-11.5%) was too high and consequently residual beta phase was encountered in the as-cast material.

5. Therefore, interest turned to a cast nickel-aluminum bronze alloy of lower aluminum content (MIL-B-23921; 8.5-9.5% Al) with equivalent alloying additions of nickel and iron since it was considered that the elimination of the dealuminization corrosion tendencies would be of greater significance than a slight reduction in strength properties. This alloy was investigated by the Laboratory and found to be susceptible to a severe surface pitting corrosion attack. The losses in strength due to this surface pitting were comparable to those encountered in alloys susceptible to dealuminization (references (e) and (f)). NASL felt that this attack was due to a non-uniform distribution of the microstructural phases and, in particular, to regions in the microstructure with high concentrations of kappa (a complex phase introduced by the Ni and Fe additions) and beta phases.

6. The duplex heat treatment (1625°F (2 hr) W.Q.-1125°F (1½ hr) W.Q.) which was successful in eliminating dealuminization tendencies in the MIL-B-16033 class alloys was not effective in eliminating the surface pitting corrosion susceptibility of the MIL-B-23921 bronze alloy. An additional problem area was discovered when the heat-affected zone of as-welded specimens was found to suffer from dealuminization after one year exposure in sea water. In an attempt to improve the pitting corrosion resistance and to eliminate dealuminization in the heat-affected zone, the Laboratory, in reference (f), recommended a heat treatment (1300°F (3 hr) Furnace Cool) be applied to all castings and weldments produced under specification MIL-B-23921.

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It was felt that this heat treatment would serve to homogenize the cast microstructure by eliminating the regions of high concentrations of secondary phases (kappa and beta). In addition, the amount of dealuminization prone beta phase encountered in the heat-affected zone of weldments would be reduced upon application of this heat treatment. This recommendation was accepted and has been incorporated into Military Specification MIL-B-23921 (reference (h)).

7. In order to determine the effect of alloy composition on the pitting corrosion tendencies of nickel-aluminum bronze, and to evaluate the effectiveness of the aforementioned homogenization the treatment, NASL initiated an investigation, the results of which are reported herein.

#### ACKNOWLEDGEMENT

8. The authors wish to express their appreciation to Messrs. G. Sorkin and B. B. Rosenbaum of the Naval Ship Systems Command and Messrs. H. S. Sayre and F. Rosenthal of the Naval Ship Engineering Center, for sponsoring and encouraging the program which served as the basis for this report. Special acknowledgement is due to Messrs. R. J. Severson and C. Dralle of Ampco Metal Incorporated, Milwaukee, Wisconsin, who supplied the alloys used in this investigation at no cost to the Navy. For his assistance in the metallographic studies, Mr. P. J. Frintzilas of NASL is also acknowledged.

#### OBJECTIVE

9. The objectives of the work reported herein are to determine the effects of chemical composition, foundry practice, and heat treatment on the sea water corrosion resistance of NASL modified nickel-aluminum bronze casting alloys.

#### PROCEDURE

10. Material. The materials utilized in this investigation consisted of four (4) cast nickel-aluminum bronze alloys prepared to NASL specifications by Ampco Metal Incorporated, Milwaukee, Wisconsin. The alloys were supplied to NASL in the form of 1"x1"x6" bars removed from standard keel-block castings (reference (i) - Method 211.1, Figure 12c). The producer's chemical analyses of the four bronze alloys are presented in Table 1.



11. Conditions Studied. In order to determine the effect of cooling rate on the resultant corrosion and tensile properties, one half of the keel-block castings were "shaken out" of the mold at approximately 1300°F and allowed to air cool; the remainder were allowed to cool overnight to room temperature. Various thermal treatments were applied to 1"x1"x $\frac{1}{2}$ " slugs, cut from the cast test bars, in order to determine an optimum heat treatment for each alloy. The following table summarizes the conditions studied in this investigation:

	<u>AS - CAST</u>	<u>HEAT TREATED</u> (1)
Alloy 95 -	Slow Cool; Fast Cool	1300°F (3 hr)F.C.(2)
Alloy 96 -	Slow Cool; Fast Cool	1400°F (3 hr)F.C.
Alloy 97 -	Slow Cool; Fast Cool	1400°F (3 hr)F.C.
Alloy 98 -	Slow Cool; Fast Cool	1300°F (3 hr)F.C.

(1) All heat treatments performed on slow cooled material, (based on microstructure).

(2) F. C. - Furnace Cool.

12. Preparation of Test Specimens. From each of the 1"x1"x6" keel-block test bars, two (2) flat tensile specimens were machined. A sketch of the test specimen is given in Figure 1. Four (4) specimens were prepared for each of the conditions studied. Specimens representing heat treated conditions were machined after the coupon had received its designated heat treatment.

13. Testing. The following tests were performed on the four modified nickel-aluminum bronze alloys:

(a) Sea Water Corrosion - Two test specimens for each of the conditions studied were forwarded to the Harbor Island Corrosion Test Station, Wrightsville Beach, North Carolina for six month immersion in flowing sea water (approx. 3 ft/sec.)(1) Specimens were cleaned and weighed prior to exposure. Upon removal from sea water, the specimens were cleaned, re-weighed and photographed. Due to the pitting type corrosion encountered, the depth of pitting was measured on each sample and reported as both maximum and average values.

(b) Tensile Testing - All tensile tests were conducted in accordance with reference (1). Specimens were tested in the unexposed condition to establish control properties. After six month sea water exposure, specimens were tested to determine the effects of corrosion on tensile properties.

(1) Ampco Metal Inc. arranged for corrosion testing and shipment of test specimens.

14. Metallography. For each condition studied, photomicrographs were taken on samples removed from the shank ends of the control tensile specimens. In the case of the exposed tensile specimens, excessive crevice corrosion was encountered on the shank ends. Consequently, metallographic samples were removed from the gage sections of these specimens after tensile testing. All etching was performed using a 10% solution of ammonium persulfate in water and the etchant was applied by immersion of the specimen in the solution.

#### RESULTS

15. Microstructure. The microstructures of the four modified nickel-aluminum bronze alloys studied in this investigation are presented in Figure 2. All the alloys contain the alpha, beta and kappa phases in their as-cast microstructures. However, the size, shape and distribution of these phases are a function of alloy composition, rate of cooling in the mold and heat treatment.

16. Fast cooled as-cast microstructures contain acicular alpha grains surrounded by dense networks of "pearlitic" or lamellar kappa and residual beta phases. The microstructures of the alloys allowed to slow cool in the mold indicate a general decrease in the amount of the secondary phases (kappa and beta) present. This is attributed to the transformation of residual beta to alpha plus kappa and to the spheroidization of the lamellar kappa phase upon slow cooling.

17. Application of a 1300°F or 1400°F heat treatment to the slow cooled as-cast material (Figure 2) results in a homogenization of the microstructure. This homogenization is marked by (a) precipitation of fine kappa phase within the alpha grains, (b) elimination of the beta and kappa phase networks, and (c) spheroidization of lamellar kappa phase. The identity of the black etching constituent present in the microstructures of Alloy 95 and the slow cooled and tempered microstructures of Alloy 97 is not known, but examination at high magnifications suggests that this constituent may well be a massive form of kappa phase. This constituent will be discussed at greater length later in the report.

18. Surface Appearance. In all cases, the four alloys tested exhibited appreciable crevice corrosion on the shank ends of the specimens after six month sea water exposure. This is not unusual in view of the fact that the specimens were supported during immersion on wooden racks which made contact at the shank ends. For this reason, attention was centered on the gage length portions of the specimens. There were significant differences in the appearance of the gage lengths from alloy to alloy, as illustrated in Figure 3.

19. Both Alloy 95 and Alloy 97 in the as-cast conditions displayed relatively severe surface pitting corrosion after sea water exposure. On the other hand, as-cast alloys 96 and 98 were free from any significant surface attack, other than the crevice corrosion mentioned above. For a given alloy there was little visible difference in pitting corrosion attack between the slow cooled and fast cooled as-cast test specimens. This was surprising in view of the fact that the microstructures indicated differences in the distribution of the phases as well as in alpha grain size, i.e., see Figure 2, Alloy 97, fast cool vs. slow cool as-cast.

20. When the as-cast material was compared to specimens which received homogenization treatments (1300°F or 1400°F) it appeared that the alloys susceptible to pitting corrosion remained susceptible after heat treatment, but the resistance to pitting was definitely improved. As was expected, the alloys which were almost unmarked by pitting in the as-cast condition (NASL Alloys 96 and 98) showed no visible change in surface appearance as a result of thermal treatments.

21. Corrosion Measurements. The relative sea water corrosion resistance, of the four modified nickel-aluminum bronze alloys studied, is expressed in terms of weight loss and maximum depth of pitting in Table 2. Considering the weight loss data first, the slow cooled as-cast material appears relatively more resistant to sea water corrosion than material in the fast cooled as-cast condition, regardless of the alloy being considered. This difference between the as-cast conditions was not apparent from a visual examination of the specimens.

22. Weight loss data indicate that as-cast Alloys 96 and 98 are most resistant to sea water corrosion. This is in agreement with prior visual appraisal of the alloys. Furthermore, there appears to be no significant difference in the corrosion resistance of Alloy 96 and Alloy 98. With regard to as-cast Alloys 95 and 97, their corrosion resistance appears to be inferior.

23. Heat treatment at 1300°F and 1400°F resulted in improved resistance to pitting attack (loss of metal) during sea water exposure when compared to the as-cast conditions. The heat treatment appeared to be most beneficial on Alloys 95 and 97 by reducing the amount of metal loss during sea water exposure. Thus, weight loss data illustrates the effectiveness of the low temperature homogenization treatment.

24. Depth of pitting measurements were reported for academic information and not for the purpose of evaluating the relative corrosion resistance of the alloys. In any event, indications are that significant depth of pitting may be encountered in nickel-aluminum bronzes.

25. Tensile Tests. Results of tensile tests conducted on control and six month exposed specimens are presented in Table 3. After six month sea water exposure, it was noted that the percent elongation displayed by the exposed specimens was consistently higher than that of the corresponding control specimens. Tensile strength values of the exposed specimens remained practically unchanged when compared with the control samples. The only property which appeared to be reduced by the corrosion exposure was the yield strength.

#### DISCUSSION OF RESULTS

26. The results of this investigation are summarized on Table 4, which shows the effect of chemical composition on the corrosion resistance of the NASL modified nickel-aluminum bronze alloys. It appears that both aluminum and iron have a strong influence on the pitting corrosion resistance of these alloys. The effect of aluminum is illustrated by a comparison of Alloy 95 (9.4% aluminum) to Alloy 96 (9.9% aluminum). Both materials contained equivalent amounts of iron and nickel; however, the higher aluminum content alloy displayed far superior pitting corrosion resistance. The effect of iron on pitting corrosion is illustrated by comparison of Alloys 97 (6% iron) and 98 (4% iron) which contain equivalent amounts of aluminum and nickel.

This indicates that excessive iron is detrimental to pitting corrosion resistance (even in the presence of 9.9% aluminum, which was shown to be adequate for Alloy 96). Thus, it appears that the alloy composition must be balanced with regard to aluminum, iron and nickel in order to achieve adequate pitting corrosion resistance.

27. Evidence in favor of an upper limit for the iron content is found in the microstructures of Alloy 95 and Alloy 97, which reveal a massive black-etching constituent that often takes the appearance of large rosettes (Paragraph 17). One such massive particle is illustrated in Figure 4. The shape is typical of the phase which has been called Fe-rich kappa (reference (g)). The massive constituent is also characterized by its tendency to be found in the center of alpha grains. From the above observations, it is felt that both Alloys 95 and 97 contain iron in excess of the amount which the alloy composition will tolerate. Thus, the iron appears to have segregated and formed massive particles of Fe-rich kappa. These massive particles may impair corrosion resistance by acting as sites for pitting corrosion to initiate.

28. It should be noted that the pitting corrosion attack was concentrated on those regions of the microstructure which contained high concentrations of kappa and beta phases. Microscopic examination further revealed that in some instances the beta phase was subject to dealuminization. However, the extent of the attack was minor and relatively scattered. This is verified by the absence of dealuminization on the fracture surfaces of the exposed specimens.

29. Variation in the iron-to-nickel ratio from 0.8 to 1.2 at the same level of aluminum did not affect the corrosion resistance of the alloys unless the iron content was far in excess of 5% at the 9.9% aluminum level. This is illustrated by comparison of alloys 96, 97 and 98 (Table 4). The effect of nickel content on the aluminum-iron balance has not been ascertained in this investigation, however, it is certain that nickel will have an effect on the balance.

30. The results of tensile tests (Table 3) were puzzling in view of a lack of any significant reductions in strength as a result of the pitting corrosion encountered in Alloys 95 and 97. This led to the comparison which appears in Table 5. Data provided by Ampec on 0.505" diameter control tensile specimens were compared to NASL's flat tensile control values and in all cases the flat type specimens

exhibited higher yield and lower tensile strengths than the corresponding round specimens. In addition, the ductility of the flat type specimens was significantly lower than that exhibited by the 0.505" diameter specimens. It was concluded that the flat tensile specimens used to establish the control properties did not demonstrate the true tensile properties of the alloys as demonstrated by the values obtained on 0.505" diameter specimens. Therefore, the effects of sea water corrosion on the tensile properties of the NASL modified nickel-aluminum bronzes were not considered. The reason for the unusual behavior of the flat control bars may be attributed to the method by which these test bars were removed from the 1"x1"x6" keel block casting legs.

31. The effect of homogenization heat treatments (i.e., 1300°F or 1400°F for 3 hrs) on the corrosion resistance of the modified nickel-aluminum bronzes may be evaluated on the basis of weight loss data. While the weight loss data reported in Table 2 reflect the effects of both pitting and crevice corrosion, the improvement in overall corrosion resistance as a result of heat treatment is nonetheless apparent. This improvement is attributed to a homogenization of the as-cast microstructure at the heat treating temperature. The resultant structure is relatively free from regions of high concentrations of beta and kappa phases which were targets for pitting corrosion attack in the as-cast material.

32. Weight loss data also revealed that the slow cooled as-cast alloys have better corrosion resistance than the fast cooled alloys. This is attributed to additional time at relatively high temperature (approximately 1300°F) which allows the microstructure of the slow cooled material to become more homogeneous than its fast cooled counterpart.

#### CONCLUSIONS

33. As a result of the work performed in this investigation the following conclusions are drawn with regard to the NASL modified cast nickel-aluminum bronzes:

a. For given levels of nickel and iron, resistance to pitting corrosion increases with increasing aluminum content.

b. For given levels of nickel and aluminum, resistance to pitting corrosion decreases with increasing iron content.

c. Chemical composition must be properly balanced with respect to the aluminum, iron and nickel contents in order to achieve adequate resistance to pitting corrosion.

d. Slow cooled as-cast alloys display better sea water corrosion resistance than alloys "shaken-out" of the mold at approximately 1300°F and allowed to air cool.

e. Heat treatment at 1300°F or 1400°F (depending on the alloy composition) increases the corrosion resistance over that of the as-cast material.

#### RECOMMENDATIONS

34. In view of the dependence of pitting corrosion on the aluminum and iron contents of the modified nickel-aluminum bronze, it is recommended that a thorough investigation be initiated aimed at developing an aluminum bronze alloy with adequate pitting and dealuminization corrosion resistance by quantitatively defining the compositional limits on aluminum, iron and nickel.

35. As a result of the improvement in sea water corrosion resistance associated with the heat treatments given to the NASL modified alloys in this investigation, it is recommended that castings produced under specification MIL-B-23921, continue to receive the specified 1300°F (3 hr) F. C. heat treatment. (Reference (h)).

#### FUTURE WORK

36. The Laboratory is currently preparing a series of alloys in order to study in detail the effects of aluminum, iron and nickel on the sea water corrosion resistance, tensile properties and weldability of cast nickel-aluminum bronze. Corrosion specimens will be forwarded to the Harbor Island Corrosion Test Station for six month and one year immersion in flowing sea water. It is anticipated that the results of investigations on the unexposed material will be reported by December 1967. In addition, this report will encompass the effects of a 1300°F (3 hr) F. C. heat treatment on the tensile properties and microstructure of the alloys.

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TABLE 1 - Producer's Chemical Analyses of NASL Modified Ni-Al Bronze Alloys.

NASL ALLOY	CHEMICAL COMPOSITION <sup>(1)</sup> (Weight %)					
	Cu	Al	Fe	Ni	Mn	Si
95	79.90	9.40	5.36	4.55	0.77	0.02
96	79.69	9.87	5.22	4.44	0.78	- -
97	78.40	9.90	5.87	5.02	0.80	0.01
98	80.54	9.85	3.87	4.92	0.80	0.02

Note: (1) Analyses supplied by Ampco Metal Inc., Milwaukee,  
Wisconsin.



TABLE 2 - Effect of Six Month Sea Water Exposure on Modified Ni-Al-Bronze Alloys.  
(Data Submitted by INCO Harbor Island Corrosion Test Station).

CONDITION OF MATERIAL	WEIGHT LOSS <sup>(1)</sup> (Grams)	DEPTH OF PITTING <sup>(2)</sup> (Inches; Max.)
NASL ALLOY 95		
As-Cast (Slow Cool)	4.25	0.019
As-Cast (Fast Cool)	5.47	0.023
1300°F (3 Hr) F.C.	2.54	0.005
NASL ALLOY 96		
As-Cast (Slow Cool)	2.53	0.011
As-Cast (Fast Cool)	3.74	0.011
1400°F (3 Hr) F. C.	2.09	0.003
NASL ALLOY 97		
As-Cast (Slow Cool)	4.27	0.007
As-Cast (Fast Cool)	5.05	0.008
1400°F (3 Hr) F. C.	2.65	0.019
NASL ALLOY 98		
As-Cast (Slow Cool)	2.19	0.003
As-Cast (Fast Cool)	3.39	0.003
1300°F (3 Hr) F. C.	2.20	0.003

Note: (1) Average of Two Specimens.

(2) Depth of Pitting on Gage Length of Tensile Specimens.

## U.S. NAVAL APPLIED SCIENCE LABORATORY

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Before and After Sea Water Exposure.

CONDITION OF MATERIAL	EXPOSURE PERIOD	TENSILE PROPERTIES <sup>(1)</sup>		
		YIELD STRENGTH <sup>(2)</sup> (KSI)	TENSILE STRENGTH (KSI)	ELONGATION (% in 2")
NASL ALLOY 95				
As-Cast (Slow Cool)	Control	41.0	87.0	11.0
	6 Months	35.8	84.8	13.0
As-Cast (Fast Cool)	Control	41.5	90.0	10.0 <sup>(3)</sup>
	6 Months	37.8	92.5	15.0
1300°F(3Hr)F.C.	Control	44.7	94.2	10.0
	6 Months	42.2	95.5	15.0
NASL ALLOY 96				
As-Cast (Slow Cool)	Control	43.5	90.1	10.0
	6 Months	40.1	94.5	16.0
As-Cast (Fast Cool)	Control	41.7	96.6	14.5
	6 Months	41.0	97.4	16.5
1400°F(3Hr)F.C.	Control	43.1	91.3	10.5
	6 Months	39.6	93.6	15.0
NASL ALLOY 97				
As-Cast (Slow Cool)	Control	43.3	88.8	8.0
	6 Months	39.8	89.9	12.0
As-Cast (Fast Cool)	Control	45.5	90.7	8.0
	6 Months	41.7	93.9	12.0 <sup>(3)</sup>
1400°F(3Hr)F.C.	Control	43.0	94.8	12.0
	6 Months	40.9	90.4	11.0
NASL ALLOY 98				
As-Cast (Slow Cool)	6 Months	41.2	94.7	16.0
As-Cast (Fast Cool)	Control	44.5	96.3	10.0
	6 Months	42.3	96.4	16.0
1300°F(3Hr)F.C.	Control	46.5	95.4	10.0
	6 Months	43.6	97.4	16.0

Note: (1) Flat Tensile Specimens as shown in Figure 1.  
 (2) 0.005% Extension Under Load.  
 (3) One Determination.

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TABLE 4 - Relative Corrosion Resistance of Modified Nickel-Aluminum Bronzes  
As a Function of Chemical Composition.

NASL ALLOY	CHEMICAL COMPOSITION <sup>(1)</sup>			Fe-to-Ni RATIO	RELATIVE CORROSION RESISTANCE
	Al	Fe	Ni		
95	9.4	5.4	4.5	1.2	Poor
96	9.9	5.2	4.4	1.2	Excellent
97	9.9	5.9	5.0	1.2	Poor
98	9.9	3.9	4.9	0.8	Excellent

Note: (1) Approximate or Nominal Composition.

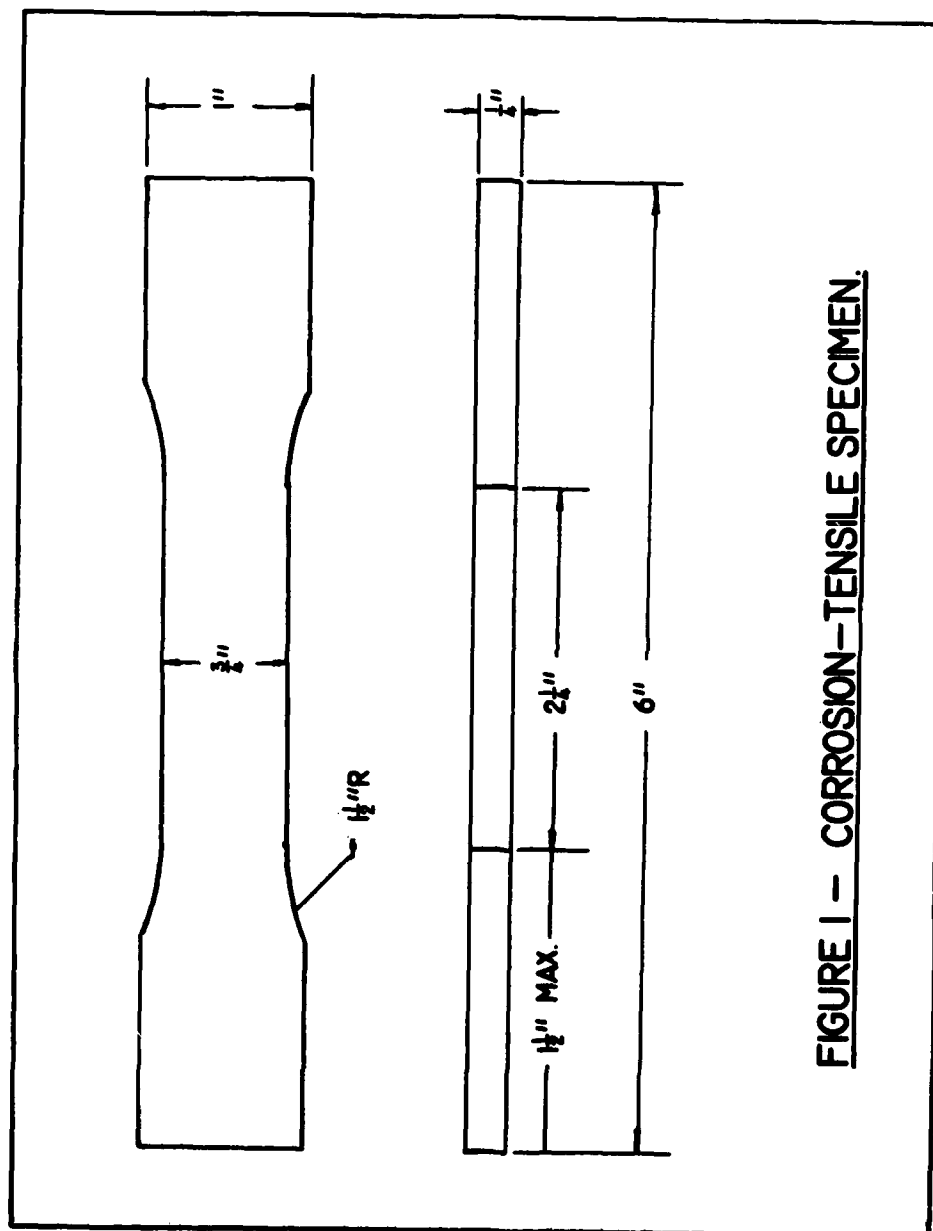
TABLE 5 - Effect of Test Bar Geometry on Control Tensile Properties of  
Modified Nickel-Aluminum Bronze Alloys.

CONDITION OF MATERIAL	SPECIMEN TYPE	TENSILE PROPERTIES		
		YIELD STRENGTH <sup>(1)</sup> (KSI)	TENSILE STRENGTH (KSI)	ELONGATION (% in 2")
NASL ALLOY 95				
As-Cast (Slow Cool)	Round <sup>(2)</sup>	38.0	96.0	21.0
	Flat <sup>(3)</sup>	41.0	87.0	11.0
As-Cast (Fast Cool)	Round	39.0	99.0	22.5
	Flat	41.0	90.0	10.0
NASL ALLOY 96				
As-Cast (Slow-Cool)	Round	40.5	100.0	22.5
	Flat	43.5	90.1	10.0
As-Cast (Fast Cool)	Round	42.0	104.5	22.5
	Flat	41.7	96.6	14.5
NASL ALLOY 97				
As-Cast (Slow Cool)	Round	42.0	99.0	18.0
	Flat	43.3	88.8	8.0
As-Cast (Fast Cool)	Round	42.0	103.5	18.0
	Flat	45.5	90.7	8.0
NASL ALLOY 98				
As-Cast (Fast Cool)	Round	44.0	101.0	18.0
	Flat	44.5	96.3	10.0

Notes: (1) 0.005% Extension Under Load.

(2) 0.505" Diameter Specimen - Data supplied by Ampco Metal Inc.

(3) Flat Tensile Specimen as shown in Figure 1.



**FIGURE 1 — CORROSION-TENSILE SPECIMEN.**

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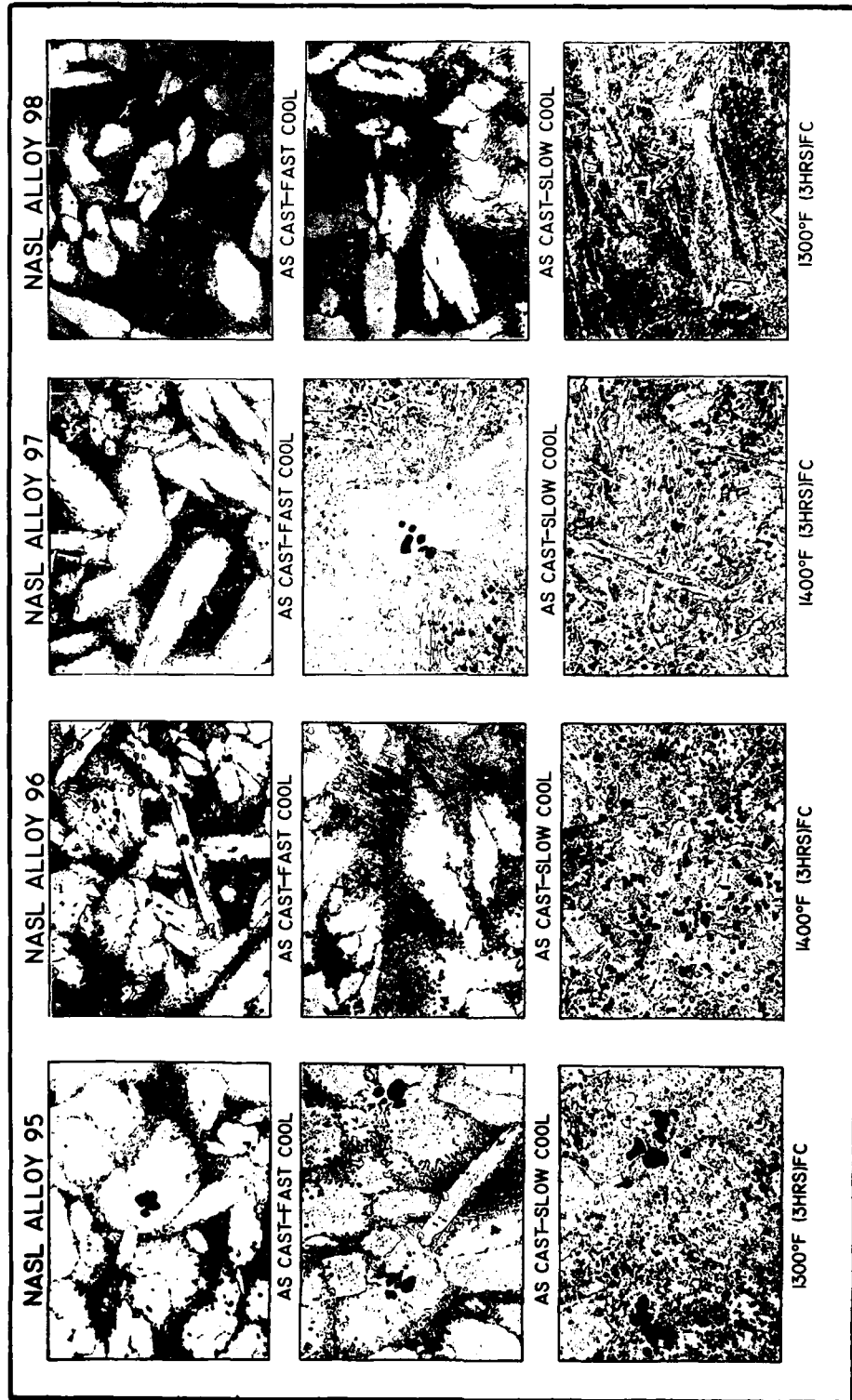


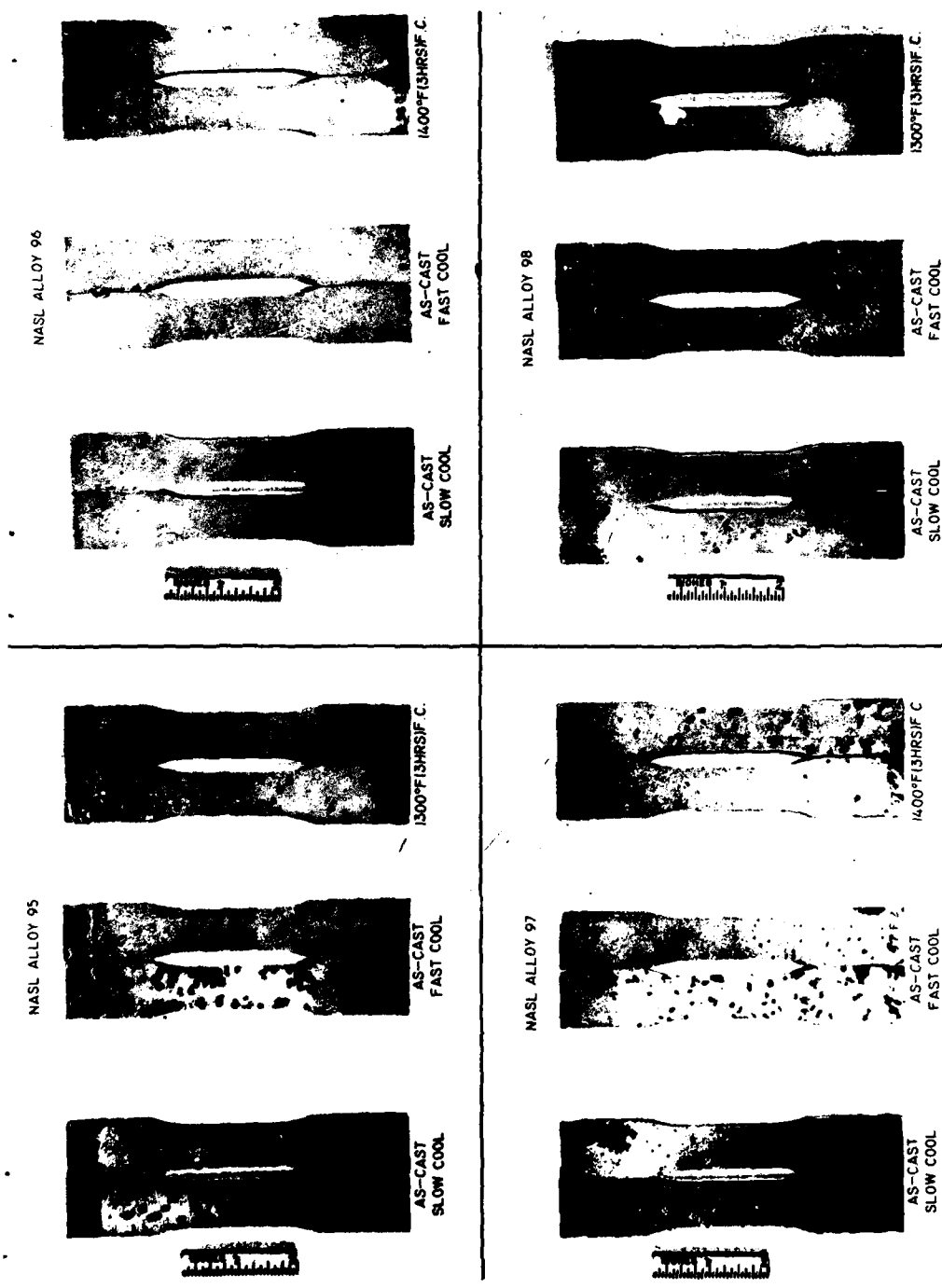
FIGURE 2-STRUCTURES OF NASL MODIFIED NICKEL-ALUMINUM  
BRONZE ALLOYS. 500X (REDUCED ONE HALF)

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**FIGURE 3—NASL MODIFIED NICKEL—ALUMINUM BRONZE CORROSION SPECIMENS AFTER SIX MONTH EXPOSURE IN FLOWING SEA WATER.**



2000X

FIGURE 4--MASSIVE, BLACK ETCHING CONSTITUENT  
IN AS-CAST ALLOY 95

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## 13. ABSTRACT

Flowing sea water corrosion tests were conducted on four cast modified nickel-aluminum bronzes in order to determine the effects of variation in alloy composition and heat treatment on pitting corrosion tendencies. It was found that the aluminum and iron contents controlled the pitting corrosion resistance of these alloys. A proper balance of the major alloying elements appeared necessary to insure adequate corrosion resistance. Heat treatment at 1300°F and 1400°F improved the overall corrosion resistance over that of as-cast alloys. In addition, it was observed that slow cooled cast material displayed better as-cast corrosion resistance than fast cooled material.

<p>U.S. Naval Applied Science Laboratory. Project 930-76. EFFECTS OF CHEMICAL COMPOSITION AND HEAT TREATMENT ON THE SEA WATER CORROSION RESISTANCE OF CAST MODIFIED NICKEL-ALUMINUM BRONZE, by C. A. Zanis, M. L. Foster and J. R. Grisoli. Progress Report 3, 21 August 1967, 27 p. illus. UNCLASSIFIED</p> <p>Flowing sea water corrosion tests were conducted on four cast nickel-aluminum bronzes to determine the effects of variation in alloy composition and heat treatment on pitting corrosion. It was found that the aluminum and iron contents controlled pitting corrosion resistance. A proper balance of the major alloying elements appeared necessary to insure adequate corrosion resistance. Heat treatment improved the overall corrosion resistance. Slow cooled cast material displayed better as-cast corrosion resistance than fast cooled material.</p>	<p>1. Corrosion Resistant Alloys - Metallurgy 2. Corrosion Resistant Alloys - Test Results 3. Bronze Castings - Corrosion I. Zanis, C. A. II. Foster, M. L. III. Grisoli, J. R. IV. SP-020-01-02; Task 0727</p>	<p>U.S. Naval Applied Science Laboratory. Project 930-76. EFFECTS OF CHEMICAL COMPOSITION AND HEAT TREATMENT ON THE SEA WATER CORROSION RESISTANCE OF CAST MODIFIED NICKEL-ALUMINUM BRONZE, by C. A. Zanis, M. L. Foster and J. R. Grisoli. Progress Report 3, 21 August 1967, 27 p. illus. UNCLASSIFIED</p> <p>Flowing sea water corrosion tests were conducted on four cast nickel-aluminum bronzes to determine the effects of variation in alloy composition and heat treatment on pitting corrosion. It was found that the aluminum and iron contents controlled pitting corrosion resistance. A proper balance of the major alloying elements appeared necessary to insure adequate corrosion resistance. Heat treatment improved the overall corrosion resistance. Slow cooled cast material displayed better as-cast corrosion resistance than fast cooled material.</p>	<p>1. Corrosion Resistant Alloys - Metallurgy 2. 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